Research Projects
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Spin Supersolid phase in Heisenberg spin systems
The detection of possible supersolid (SS) state in solid ^{4}He has led to a resurgence of interest in this novel state of matter that has never been conclusively observed in nature. While the fate of the SS phase in the continuum (solid ^{4}He) remains inconclusive, it has been shown that this phase can be stabilized in the presence of an external lattice. The recent breakthroughs in observing Bose-Einstein condensation and other novel phases in spin dimer compounds motivated us to extend the search of supersolid phase to magnetic systems. Our results show that a spin supersolid ground state (with simultaneous XY and Ising ordering) can be stabilized by a uniform external magnetic field in S=1 Heisenberg spins with strong exchange and single ion anisotropies. We also derived the conditions under which real spin compounds can develop supersolid order. The key ingredients necessary are $S = 1$ a *dimerized* structure and a *frustrated* inter–dimer coupling. Currently, we are working closely with the experimental group at the National High Magnetic Field Laboratory (NHMFL) at LANL to identify real materials with the appropriate structure which can then be used to test our theoretical predictions.

In a subsequent study, we used an analytical approach (with supproting numerical simulations) to obtain exact results for the spin supersolid phase in an S=1 Heisenberg chain with strong exchange and single ion anisotropies. This is surprising considering that 1D solid phases are usually unstable when the particle density (magnetization for spin systems) deviates from the corresponding commensurate value because each added (or removed) particle introduces a soliton in the ground state. Furthermore, the analytical results also provide a deeper insight into the mechanism behind the formation of the spin supersolid.

Quantum magnetism in high magnetic fields:
The interplay between competing interactions, geometric frustration and strong magnetic fields leads to several novel phases and associated phenomena in spin systems, especially in low dimensions. Over the past one year, I have been working with different experimental groups at the NHMFL to understand the be behavior of several of these compounds.

(a) *Magnetization plateaus in* $SrCu_2(BO_3)_2$: Recent measurements by N. Harrison (LANL) and S. Sebastian (Cambride U., UK) in high fields (up to 85 T) and at very low temperatures (35 mK) have revealed a sequence of quantum hall-like plateaus at $1/q; 2 \leq q \leq 9$ and $p/q = 2/9$ fractions in the magnetization with increasing magnetic fields in this highly frustrated spin compund. Using an unconstrained Chern-Simons theory, we are able to explain the emergence of the plateaus and predict the magnetization modulation pattern that can be verified by future NMR experiments at high fields.

(b) *Dimensional reduction in* $BaCu(SiO_3)_2$: Because of frustrated inter-layer couplings, this layered compound (also known as Han purple) undergoes a dimensional reduction at low temperatures whereby the layers are effectively decoupled. As a result, the field induced BEC transition belongs to the 2D universality class and explains the observed anomaly in the measured critical exponents. With Cristian Batista and Joerg Schmalian, we have developed a complete theory of the dimensional reduction using analytical and numerical approaches and tested the validity of the theory by comaring our theoretical predictions with experimental observations in $BaCu(SiO_3)_2$.

(c) *Magnetostriction measurements in* $NiCl_2$-$4SC(NH_2)_2$: Working with Vivien Zapf

(LANL), we showed that the magnetostriction measurements in $NiCl_2$-$4SC(NH_2)_2$ can be used to estimate the magnetic energy as the field is varied across the entire range over which this compound exhibits field-induced BEC.

(c) *ESR measurements in* $NiCl_2$-$4SC(NH_2)_2$: ESR has long been used as a tool for elucidating the magnetic structure of materials. Comparing (quantitatively) the experimental data of Ross McDonald (LANL) and Steve Hill (U. Florida) with numerical calculations, we have developed a microscopic model for the compound with accurate estimates of all the interaction parameters.